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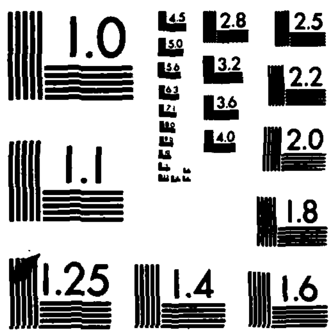
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USAARL REPORT NO. 84-2

COMPARISON OF REAL-EAR ATTENUATION CHARACTERISTICS OF THE STANDARD SPH-4 EARCUP AND A PROTOTYPE CRUSHABLE EARCUP

By

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December 1983

U.S. ARMY AEROMEDICAL RESEARCH LABORATORY
FORT RUCKER, ALABAMA 36362

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ABSTRACT:

The use of the SPH-4 aviator's helmet in the Army is to provide hearing protection, voice communications, and head protection against impact. Efforts have been made recently to improve impact protection in the region of the earcup. In 1977, USAARL contracted with Simula Incorporated to develop an earcup which would provide greater energy absorption on impact and still provide sound attenuation equivalent to the current standard earcup. A prototype has been submitted for evaluation of noise attenuation and comparison to the current standard earcup. The crushable earcup was found to provide greater hearing protection at most test frequencies.

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INTRODUCTION

The SPH-4 aviator's helmet (MIL H-43925) currently in use in the Army provides hearing protection, voice communications, and head protection against impact. However, it has been recognized that impact protection is significantly compromised in the region of the earcup (Haley, et al., 1983). In 1977, the United States Army Aeromedical Research Laboratory (USAARL) contracted with Simula Incorporated to develop an earcup which would provide greater energy absorption for impact while providing sound attenuation equivalent to the earcups in the current SPH-4 helmet. Proposed production samples (Simula Assembly Number 100756-3) resulting from that contract were submitted for testing. This report will discuss the results of sound attenuation testing conducted at USAARL in accordance with the current ANSI standard to compare the prototype earcup with the current standard earcup.

METHODS AND INSTRUMENTATION

The method for determining the sound attenuation characteristics of the standard and crushable earcups was the ANSI Standard Z24.22(1957), "USA Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold" (Revised 1971). Ten listeners were selected from a pool of paid volunteers. The subject population was made up of normal hearing junior college students. A pair of each earcup type (see Figure 1, page 4) was installed in the same regular size SPH-4 helmet. The same listeners were used to evaluate the real-ear attenuation characteristics of each earcup type on different occasions.

The real-ear attenuation measurement was conducted in a custom-built Tracoustics Corporation Audiometric Examination Room measuring 10'X9'4"X6'6" (LXWXH) located at the Acoustical Sciences Research Group Laboratory, Sensory Research Division, United States Aeromedical Research Laboratory, Fort Rucker, Alabama. There was no audible ambient noise in the test room during the test period. Mean sound pressure levels in decibels (re 20μPa) of ambient noise per 1/3 octave band are listed in Table 1. The sound pressure level gradient characteristics of the test room are contained in Tables 2 through 4.

The test equipment and instrumentation are shown schematically in Figure 1. The tones were generated by a Fluke Model 1060A Synthesized Signal Generator. The output of this synthesizer was connected to the input of a Grason-Stadler 1278B electronic switch. The test tone was interrupted with a 50 percent duty cycle. The on duration and off duration were 370 milliseconds each. The rise and decay times of the signal were 40 milliseconds each. The output of the electronic switch was connected to the input of a Grason-Stadler model 1288 power amplifier. The amplifier output was connected

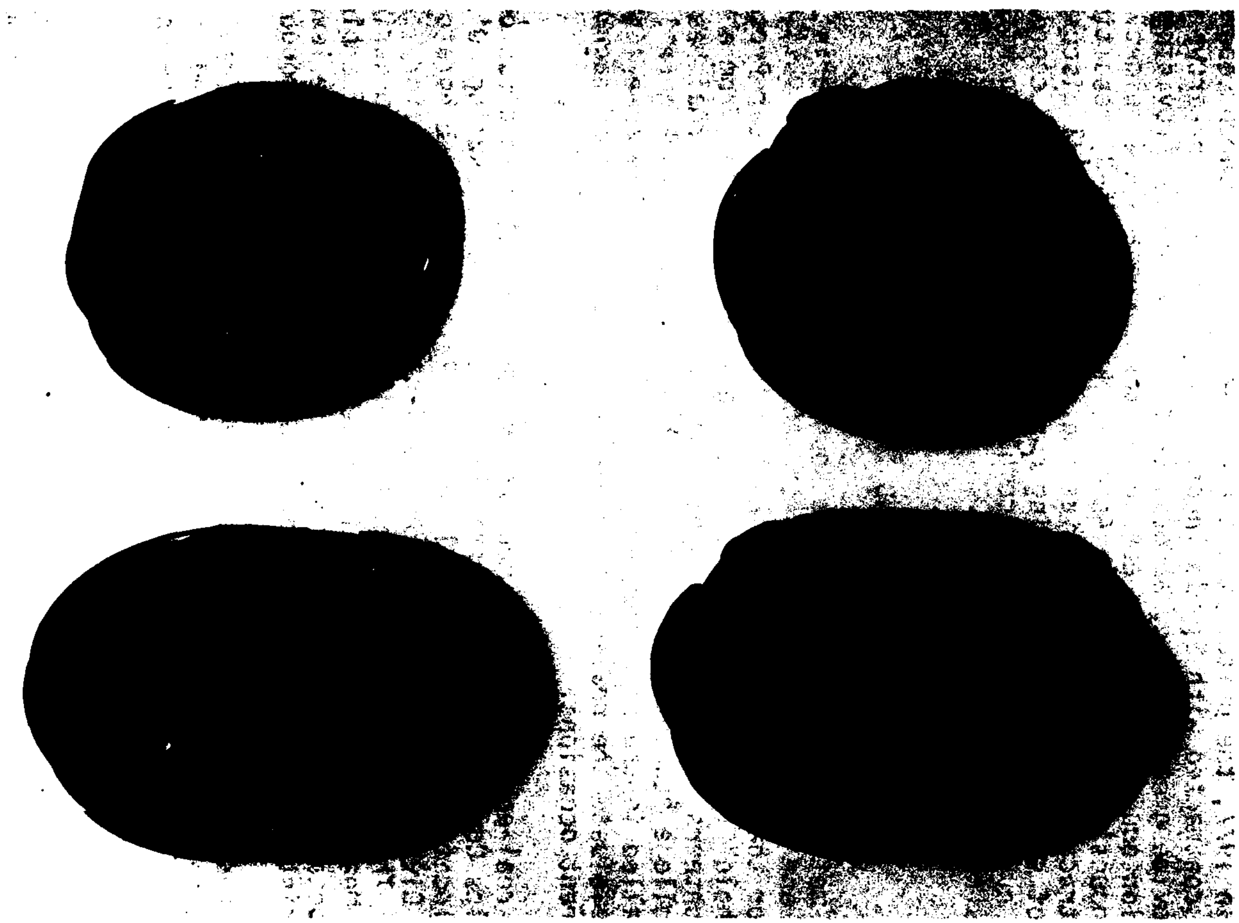

FIGURE 1. Left: End and side view of Standard SPH-4 Earcup.
Right: End and side view of Prototype Crushable Earcup.

TABLE 1

AMBIENT SOUND PRESSURE LEVELS

Mean sound pressure level values in decibels (re 20μPa) for the USAARL Tracoustics Audiometric Room. Also shown are system noise data for the instrumentation used in measuring the acoustic noise

1/3rd Octave Band Center Frequencies in Hertz	System Noise	Ambient Noise
25.0	10.00	26.00
31.5	12.00	21.80
40.0	14.00	20.20
50.0	20.60	19.84
63.0	7.84	14.81
80.0	4.77	15.29
100.0	4.29	16.38
125.0	5.43	15.02
160.0	3.07	11.86
200.0	1.27	9.86
250.0	2.50	7.54
315.0	- 0.27	3.00
400.0	- 1.07	2.23
500.0	- 1.84	0.63
630.0	- 2.12	0.73
800.0	- 3.07	- 0.66
1000.0	- 1.57	0.02
1250.0	- 2.93	- 1.21
1600.0	- 2.75	- 1.23
2000.0	- 2.05	- 0.71
2500.0	- 1.32	- 0.16
3150.0	- 0.64	0.27
4000.0	0.50	1.5
5000.0	1.57	2.07
6300.0	2.43	3.11
8000.0	1.84	2.27
10000.0	0.07	1.09
12500.0	- 0.96	0.18
16000.0	- 1.77	- 0.71
20000.0	- 3.34	- 1.62
A	11.90	13.27
B	14.80	20.00
C	22.40	31.50
LIN	25.30	40.60

TABLE 2

SOUND PRESSURE LEVELS MEASURED AT POSITIONS IN
FRONT OF AND BEHIND NORMAL HEAD POSITION AT THE FREQUENCIES INDICATED

Test Freq in Hz	Distance in Inches in Front of the Normal Head Position			Normal Head Position	Distance in Inches Behind the Normal Head Position		
	3"	2"	1"	0	1"	2"	3"
125	75.2	75.0	74.8	74.6	74.4	74.3	74.1
250	78.8	78.6	78.6	78.6	78.6	78.5	78.5
500	83.4	83.2	83.0	83.2	83.4	83.6	84.0
1000	85.0	85.2	85.0	84.1	82.6	81.7	81.8
2000	85.7	86.6	86.0	84.2	85.5	87.0	86.1
3000	87.2	87.7	87.0	87.1	87.1	85.2	85.8
4000	81.0	82.0	80.8	81.0	79.4	78.0	77.2

TABLE 3

SOUND PRESSURE LEVELS MEASURED AT POSITIONS
BELOW AND ABOVE NORMAL HEAD POSITION AT THE FREQUENCIES INDICATED

Test Freq in Hz	Distance in Inches Above the Normal Head Position						Normal Head Position	Distance in Inches Below the Normal Head Position					
	6"	5"	4"	3"	2"	1"	0	1"	2"	3"	4"	5"	6"
125	75.6	75.5	75.4	75.2	75.2	75.0	74.8	74.8	74.7	74.6	74.3	74.2	74.0
250	77.9	78.1	78.2	78.3	78.4	78.6	78.7	78.9	79.1	79.3	79.4	79.5	79.7
500	83.2	83.4	83.4	83.3	83.2	83.2	83.2	83.1	83.1	83.2	83.4	83.6	83.5
1000	80.6	81.7	82.4	83.0	83.5	84.0	84.4	84.6	84.9	84.8	83.6	83.2	83.0
2000	83.3	83.6	83.6	83.1	83.2	83.6	84.6	85.5	86.0	85.1	83.4	83.2	83.0
3000	86.0	86.4	86.4	85.7	84.7	85.7	86.8	87.4	87.8	85.3	86.0	86.4	86.7
4000	80.6	76.0	80.5	81.6	80.0	79.4	81.7	81.6	79.8	77.6	79.7	79.2	80.5

TABLE 4

SOUND PRESSURE LEVELS MEASURED AT POSITIONS TO THE
LEFT AND RIGHT OF NORMAL HEAD POSITION AT THE FREQUENCIES INDICATED

Test Freq in Hz	Distance in Inches Left of the Normal Head Position						Normal Head Position	Distance in Inches Right of the Normal Head Position					
	6"	5"	4"	3"	2"	1"	0	1"	2"	3"	4"	5"	6"
125	74.9	75.0	75.0	74.8	74.8	74.8	74.8	74.7	74.7	74.6	74.6	74.4	74.2
250	79.1	79.0	79.0	78.8	78.8	78.7	78.6	78.5	78.4	78.3	78.2	78.0	77.9
500	83.6	83.6	83.5	83.4	83.2	83.2	83.1	83.0	83.0	83.0	83.0	83.0	83.0
1000	84.4	84.4	84.4	84.2	84.2	84.1	84.1	84.0	84.0	84.0	83.9	83.8	83.8
2000	86.1	85.8	85.8	85.4	85.2	84.4	84.2	84.5	85.3	36.2	86.7	87.0	86.6
3000	86.6	87.7	87.6	84.8	84.6	85.4	87.6	88.4	88.5	88.2	87.2	85.4	84.4
4000	81.2	80.9	79.1	79.5	80.4	81.0	81.2	81.0	80.3	79.4	79.9	80.0	78.0

REAL EAR ATTENUATION TEST SYSTEM

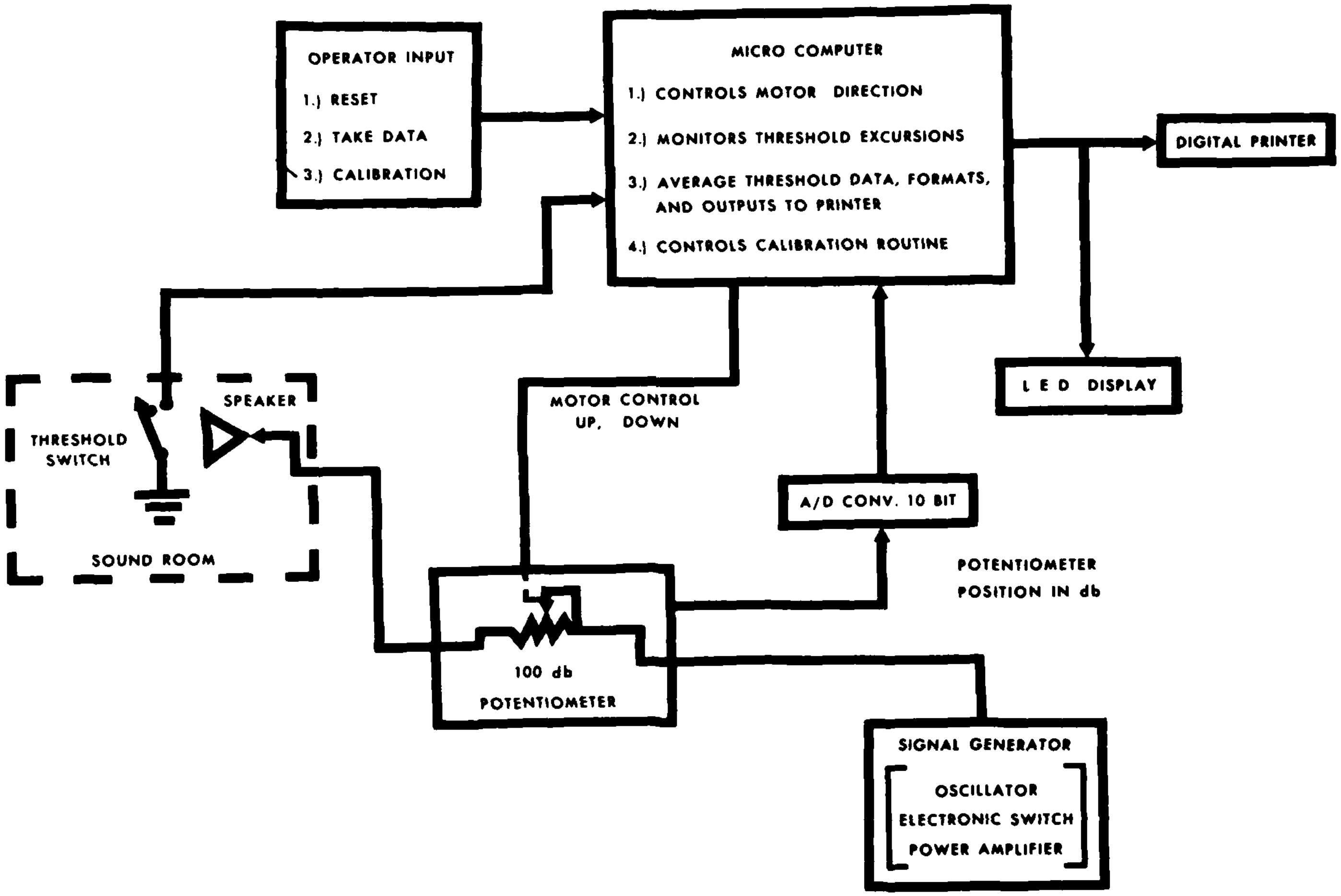

FIGURE 1. Arrangement of equipment and instrumentation used for real-ear sound attenuation testing performed at USAARL.

to a Grason-Stadler 1293 (10 ohm) step attenuator which provided the operator with a calibrated control of the test tone intensity. This allowed the operator to check listener reliability or provide additional sound intensity when testing very efficient hearing protective devices.

The step attenuator output was input to a Grason-Stadler E-3262A recording attenuator. The direction of the attenuator was controlled by the listener with a noiseless photo-electric switch. For each test sound, the listener controlled the signal level in the manner described by Von Bekesy (1947). The signal was presented via an Altec 605B 15-inch loudspeaker. The Altec speaker could produce a sound field at the listener's position which could vary from a minimum of 10 dB below the listener's unoccluded threshold to a maximum intensity of at least 10 dB above the listener's occluded threshold at all test frequencies. The voltage input to the speaker was calibrated at the beginning of each test with a Hewlett-Packard 3400A RMS Voltmeter.

The experimenter was provided with an override control of the system which allowed him to place and hold the recording attenuator at any value for purpose of training and verifying listener's reliability.

The test stimuli used were pure tones of the following frequencies: 75, 125, 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hertz.

The test listeners were required to have hearing thresholds for both ears at all test frequencies not greater than 10 dB American Standards Association (ASA 1951) as measured by a standard diagnostic audiometer. The real-ear attenuation for each type earcup was determined by taking the differences between hearing threshold values measured under two conditions. A free-field reference threshold was obtained for all frequencies with the listener facing the loudspeaker and with his head position fixed by the use of a chin rest. An attenuated threshold measurement then was made under identical conditions except that the listener wore an SPH-4 helmet which was fitted with either the standard or crushable earcup. A full standard real-ear attenuation test (three attenuation values for each test frequency for each of the 10 listeners) was run for both earcups.

A microcomputer was used to monitor the listener's responses and to average the threshold data by frequency. The computer also was used to format and output a digital printer with threshold data and to control the calibration routine.

The resulting output from the digital printer became the raw data for the experiment. These data were reduced to attenuation values by calculating the difference between the free-field thresholds and attenuated thresholds by frequency. The attenuation data then were subjected to statistical analysis.

RESULTS AND DISCUSSION

The thrust of this study was a comparison of the two earcups by frequency. Mean sound attenuation data for each cup by frequency are presented in Table 5. To determine the significance of differences between these earcups, the data were analyzed under a 10x2x10 factorial analysis of variance (ANOVA) model with a priori error rate (α) of .05. The results indicated that all main effects were significant as were all interactions. A significant main effect for frequency was expected since nearly all sound attenuating devices are more efficient at some frequencies. Similarly, the main effect for subjects was expected since hearing threshold patterns are known to vary from subject to subject. The main effect for cups suggests that the crushable earcup attenuates sound significantly better at most frequencies than the standard cup; ($F(1,400) = 30.13$, $\rho<.001$). The two-way interaction of cups with frequency was significant ($F(9,400) = 12.87$, $\rho<.001$) indicating a nonconstant difference in mean sound attenuation across frequency for the two cups.

The results of the ANOVA suggested the need for a multiple comparison. Tukey's Honestly Significant Difference (HSD) procedure was used for this purpose (Tukey, 1949). As shown in Table 5, the average attenuation is greater for the crushable earcup than the standard at all frequencies except 2000, 4000, and 6000 Hz. The results of the HSD analysis indicate that the crushable cup is as good as or significantly better than the standard SPH-4 earcup at all frequencies except 4000 and 6000 Hz, where results from the standard cup are better.

The results of this study are most important when considering the fact that obtaining adequate noise attenuation in the lower frequencies, 1000 Hz and below, is a perennial problem for two reasons: (1) attenuation is physically difficult to obtain, and (2) aircraft noise is predominantly in this range. The development of an earcup that significantly increases sound attenuation at all lower frequencies and affords greater safety from impact injury is an important achievement. It offers significant potential for reducing the incidence of job-related hearing loss among Army aviators.

CONCLUSIONS AND RECOMMENDATIONS

The crushable earcup was found to provide significantly greater real-ear attenuation at most frequencies than the standard SPH-4 earcup. For only two test frequencies--4000 and 6000 Hz-- did the crushable earcup provide significantly less attenuation than the standard earcup. Of particular importance is the increased hearing protection provided by the crushable ear-cup for sounds at 1000 Hz and below.

It is recommended that the new earcup be considered as a replacement for the current earcup used in the SPH-4 helmet.

TABLE 5

MEAN AND STANDARD DEVIATION VALUES OF SOUND ATTENUATION OF THE EARCUPS AND THE RESULTS OF THE ANALYSIS USING TUKEY'S HONESTLY SIGNIFICANT DIFFERENCE PROCEDURE

		Test Frequencies in Hertz									
		75	125	250	500	1K	2K	3K	4K	6K	8K
Crushable Earcup	Mean	19.5	16.6	16.5	35.0	29.9	33.1	46.2	42.9	37.6	33.0
	S.D.	5.7	5.3	3.3	3.8	5.6	6.1	5.6	8.1	8.0	9.6
Standard SPH-4 Earcup	Mean	15.0	13.1	13.6	28.7	25.5	34.0	43.3	46.4	42.0	31.4
	S.D.	6.9	5.8	3.7	4.2	4.6	4.4	4.1	5.1	6.7	8.1
Statistically Significant at .05		Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No

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